EFFECT OF FELDSPAR ON THE PROPERTIES OF A MEDIUM VOLTAGE CERAMIC ISOLATOR

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ABSTRACT

Feldspars addition on the breakdown voltage as well as mechanical strength of the medium voltage isolator has been investigated. The glaze properties were studied in particular its relationship to the dielectric and mechanical strengths. The breakdown voltage before and after glazing was examined. The averages breakdown voltage of ceramic body is 14.7 kV before glazing, and it increases after glazing with an average breakdown voltage ranging from 16-20 kV. Firing was done at temperature 1300 ^{0}C (with and without glazing) and six different compositions (A-F) were used in this investigation. The most positive result in this investigation was found in composition A, and the average glaze thickness is 0.318 mm with breakdown voltage of 5.51 kV (alternating current). The breakdown voltage increases linearly with the glaze thickness, and the average leaking current in this composition is 4.56 X 10^{-4}. The average porosity of ceramic body ranging from 1.0 to 5.36 percent which is quite satisfactory within the limit of experimental observation and industrial application. The averages impact strength ranging from 0.26 cm-Kg to 0.57 cm-Kg. X-ray diffraction study shows that for glaze A, sillimanite was the main phase responsible for high breakdown voltage and high impact strength, and it has orthorhombic crystal structure. While for glaze B, indialite phase was responsible for the lowest breakdown potential and lowest impact strength, and it has hexagonal crystal structure.

INTRODUCTION

Isolator is a typical material when placed between two conductors with different potential will produced extremely small leaking current or in some case not at all (Reed, 1989) . A typical isolator must have high dielectric strength, with resistivity starting from 10^{11} ohm-m. Therefore, isolator can be found in a quite number of applications, particularly for electric power transmission, and this can be categorized into; (a) power transmission electrical isolators which consist of low voltage, medium voltage, and high voltage, (b) telecommunication transmission electrical isolator and (c) microelectronic transmission isolator (Reed, 1989, Richardson, 1982, Bayer, 1980). In these applications isolator must capable to serve, as a media to hold and to separate conductors, therefore must possess mechanical strength, and resist chemical attack as well as heat, since the resistivity decline exponentially with increasing temperature. Hence, good isolator must have high dielectric strength as well as a low loss factor.

For electric power transmission application, the most important component of an isolator is the glaze properties, which covered on the top surface of the ceramic body. To facilitate electric power transmission from power stations, the transmission cable practically is sit on the top of the glaze surface. The glaze must be thin enough, in order to prevent crack during cooling after firing in the furnace from high temperature. Hairy cracks can easily be developed because of a differential thermal expansion within the ceramic body, and the glaze must be of high quality to prevent formation of pinholes, and more importantly the glaze must not vitrify after long exposure to the environment with high humidity (Parmelee, 1973). The quality of ceramic isolators depends on impurity, porosity that may be accidentally produced during blending, and firing in the furnace which can decrease its resistivity.

The properties of ceramic body depend on the size of particles and firing temperature. The basic ingredient of most ceramic consists of ball clay, kaolin and bentonite for its plasticity, feldspars, quartz, and chalk and bentonite mixture for non-plasticity (Soliman, 1972, Bayer, 1979). The basic ingredient for glaze must consist of silica (SiO_2) and mainly in the form of fritted and non-fritted glaze blended with sodium carbonate, potassium carbonate, barium carbonate, and lead oxide. For colouring other metallic minerals such as cobalt, chromium and nickel are added. Basically glaze would form a covered thin layer on top of the ceramic body during firing. There are three type of glazes such as; (a) base glaze mainly in the form of alkaline and rare earth alkaline oxides, (b) amphoteric glaze consists of amphoteric oxides in the form of boron oxide, ferric oxide and chromium oxide, and (c) acidic glaze consist of phosphoric oxide

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and zirconium oxide (Modde, 1968). The function of glaze is to prevent water absorption to the ceramic base and prevent rusting dirt to stick on the surface, because it is easily wash away by rain. The primary aims of this investigation is to obtain composition with high breakdown voltage on the ceramic body, and also to obtain glaze composition with high mechanical impact strength for industrial application and for electric power transmission line isolator.

MATERIALS AND METHODOLOGY

The base material (body) for medium voltage power transmission isolator consists of feldspars (35%), quartz (25%), kaolin (25%) and ball clay (15%) in the form of fine powder ranging from 140-200 mesh and screened by screen vibrator. Six compositions designated as composition A to F were prepared for this study and shown in Table 1., and 20 samples were prepared with composition A-F and additional 10 samples, each with A-F composition was used for each one particular testing which consists of resistivity, breakdown voltage, porosity, and x-ray diffraction measurements were carried out, and additional 10 samples with composition (A-F) were used for mechanical strength testing.

Table 1.Glaze ceramic composition

Base Material	Composition (wt%)					
	A	B	C	D	E	F
Feldspars	30	35	40	45	50	55
Quartz	40	35	30	25	20	15
Kaolin	20	20	20	20	20	20
Talcum	10	10	10	10	10	10

The sample has diameter of 40 mm with thickness 4.8 mm before firing to a temperature of 1300 ^{0}C, and subsequently after firing slight dimensional change occurred. Each sample in the form of coin is pressed by hydraulically press to a pressure of 5.0 ton, and followed by drying for 12 hours to reduce water content in order to avoid pinholes.

To study effect of feldspars on the dielectric and mechanical strengths of medium voltage power transmission isolator, several composition of feldspars were prepared as shown in the Table 2. 20 samples for each composition (A-F) were glazed and dried before firing and sintering to a temperature of 1300 ^{0}C. Firing mode is shown in Figure 1, starting from room temperature to 1300 ^{0}C, with firing time length from 0 to 14 hours with 2 hours of holding time. The physical properties and mechanical strength of glazed samples with different feldspar compositions were subsequently compared with non-glaze samples. The difference of breakdown voltage between glazed and non-glazed samples were used as an indicator of the breakdown voltage of the glaze material. Glazing was done by dipping each sample in the glaze solution, and in order to obtain fine and even glaze surface fine water mist was applied by spraying on the sample surface, and subsequently dried before sintering.

Table 2. The average sample diameter and thickness (mm) (Body with glaze composition)

Sample	Diameter	ThickNess	Areas (mm^2)
Body only	38.40	4.53	1,158.10
Body + Glaze A	38.40	4.85	
Body + Glaze B	38.40	4.77	
Body + Glaze C	38.40	4.76	
Body + Glaze D	38.40	4.84	
Body + Glaze E	38.40	4.76	
Body + Glaze F	38.40	4.75	

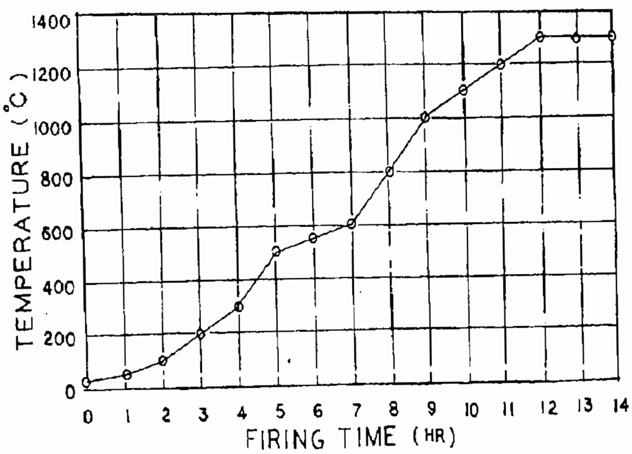

Figure 1. Firing mode of ceramic body and ceramic glaze.

Dimensional measurement after firing and sintering was done by using micrometer, and the resistivity measurement were done for both glaze and non-glaze samples with resistivity-meter. Test sample was inserted between two electrodes and the result after adjustment shown in the digital readout indicator (see Figure 2).

Breakdown voltage measurement was carried out using peak voltmeter HAEFELY type 65 with alternating current, and transformer was used (HV test System Inc) with prime voltage 220 volt and secondary voltage 100 kV with capacity 7.5 kVA and 50 Hz schematically is shown in Figure 3. Test samples were inserted between two electrodes and placed inside the shield tube, and the breakdown test was done by rising the voltage with peak voltmeter controller. The state at which the potential cannot be risen any further (because the potential fall off) indicated the breakdown voltage.

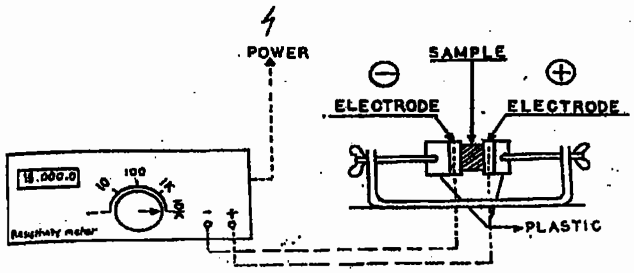

Figure 2. Resistivity-meter testing apparatus.

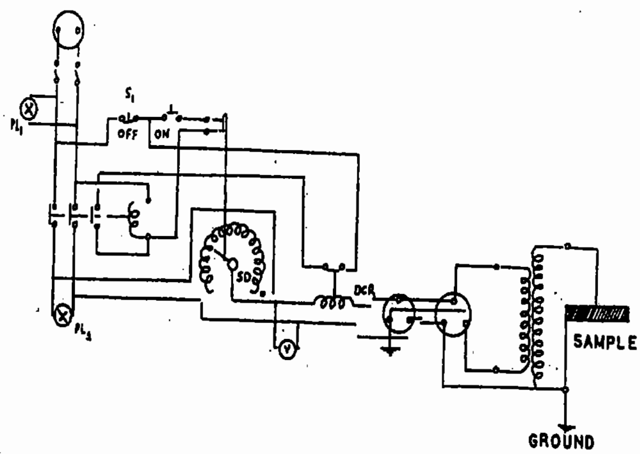

Figure 3. Peak-voltmeter for breakdown voltage measurement.

Porosity's testing was conducted to measure the effect of additional feldspars for both glaze and non-glaze samples. The main reason is that porosity has its influence on the breakdown potential. Before testing each of the samples were dried to a temperature 110 ^{0}C for 4 hours to remove moisture, and subsequently its weight is measured with microbalance. Thereafter, the samples were immersed in the boiling water for 2 hours, and then taken out and cleaned with cotton and then its weight is measure with microbalance. The difference in weight is indicative of the porosities.

Other testing was carried out, such as impact testing for both glaze and non-glaze samples. This measurement is to obtain impact load, since a variety of feldspar compositions were used for medium voltage power transmission line isolator.

RESULT AND DICUSSION

The average diameter of the test samples (without glaze) after firing at temperature of 1300 ^{0}C for 12 hours were decreased by about 2 mm, and its thickness decreases by 0.32 mm. The shrinkage is as consequences of moistures which were driven out from the ceramic body during firing. Resistivity measurement for both glaze and non-glaze samples were shown in Table 3.

Table 3. The average resistivity and breakdown voltage. (After firing at 1300° C)

Sample	Resistivity (10^7 Ohm-m)	Resistance (10^7 Ohm)	Breakdown Voltage (kV)
Body only	1.807	7.07	14.79
Body + Glaze A	1.979	8.28	20.29
Body + Glaze B	1.842	7.61	16.78
Body + Glaze C	1.933	7.94	18.24
Body + Glaze D	1.985	8.30	18.22
Body + Glaze E	1.962	8.06	18.37
Body + Glaze F	1.967	8.07	18.06

The result shows that for non-glaze (body only) it has resistivity of 1.807 X 10^7 ohmmeter and resistance 7.07 x 10^7 ohm, with breakdown voltage of 14.79 kV. The resistivity rises after glazing, and the highest resistivity was found with the glaze of composition A, which is 1.979 x 10^7 ohmmeter, and its breakdown voltage is 20.29 kV. While the lowest resistivity is found with glaze of composition B, that is 1.842 x 10^7 Ohm-meter with breakdown voltage 16.78 kV. These two compositions were subsequently examined with X-ray. From Table.1, glaze with composition A have 30 weight percent (w/o) of feldspars and 40 w/o of quartz, while for composition B it has 35 w/o of feldspars, and 35 w/o of quartz. Apparently that further addition of feldspars does not show significant improvement of the breakdown voltage, which implies that high feldspar contents do not improve the breakdown voltage. Hence, it can be said that feldspars have played a substituting role for quartz up to a certain quantity.

Further detail investigation were carried out to determine the influence of glaze with composition ranging from A to F as shown in Table. 4. The result shows that the highest resistivity and resistance was observed with glaze A which is 4.424 x 10^7 Ohm-cm and 1.211 x 10^7 ohm respectively. Glaze A has a similar thickness with glaze D (0.318 mm and 0.315 mm respectively) as well as its resistivity and resistance. Nonetheless, the breakdown voltage of glaze A is higher than the glaze D that is 5.51 kV and 3.39 kV respectively. The lowest result came with glaze B which is 1.99 kV. This result indicates that the thickness indeed is not important factor in determining resistivity and breakdown voltage, since glaze D has similar thickness to glaze B, nonetheless its breakdown voltage is higher that is 3.39 kV and 1.99 kV respectively.

Table 4. The average thickness, resistivity and breakdown voltage.
(After firing at 1300° C)

Sample	Thickness (mm)	Resistivity (10^7 Ohm-m)	Resistance (10^7 Ohm)	Breakdown Voltage (kV)
Glaze A	0.318	4.424	1.211	5.51
Glaze B	0.237	2.516	0.512	1.99
Glaze C	0.229	4.437	0.869	3.46
Glaze D	0.315	4.547	1.230	3.39
Glaze E	0.231	5.019	0.993	3.58
Glaze F	0.225	5.187	1.004	3.26

Table 5. however, shows that glaze A has dielectric strength of 173.96 kV/Cm and leak current of 4.57 x 10^{-4} ampere, and the lowest is found for glaze B which is 84.83 kV/Cm with leak current 3.89 x 10^{-4} ampere. The average porosity and mechanical strength (impact strength) were shown in the Table. 6. Although glaze B has the lowest porosity than glaze A, nonetheless glaze A has the highest impact strength compare to glaze B or others composition.

Table 5. The average body and glaze composition electrical strength

Sample	Electric Strength (kV/cm)	Leak Current (Ampere 10^{-4})
Body + Glaze A	173.96	4.57
Body + Glaze B	84.83	3.89
Body + Glaze C	152.76	3.98
Body + Glaze D	109.67	2.79
Body + Glaze E	156.52	3.61
Body + Glaze F	145.82	3.25

Table 6. The average porosity and impact strength

Sample	Porosity (%)	Impact Strength (kg-cm)
Body only	5.36	0.26
Body + Glaze A	2.70	0.76
Body + Glaze B	1.06	0.54
Body + Glaze C	4.05	0.57
Body + Glaze D	4.90	0.53
Body + Glaze E	2.21	0.31
Body + Glaze F	2.33	0.42

Further study was carried out by x-ray diffraction analysis to study detail composition and structure of non-glaze sample first, which contain mainly of quartz 0and crystoballite and is shown in Figure 4. The other sample, which gave significant difference in their properties, was examined to determine the structure and phase that formed upon firing. For glaze A, and glaze B samples (see Figure 5 and 6) x-ray diffraction study shows that sillimanite structure was the main phase and indeed was responsible for a high breakdown voltage and high impact strength. It has orthorhombic crystal structure, while in the glaze B the x-ray analysis result shows that it formed indialite phase which was responsible for the lowest breakdown potential as well as lowest impact strength, and it has hexagonal crystal structure. Detail study shows that glaze A structure consist of low quartz with a hexagonal structure, along with sillimahite phase with orthorhombic structure and indialite phase with hexagonal structure. Other phase in the ceramic body only is not detected except for crystobalite, and mullite, which have good isolator properties. In the contrary, the glaze B upon firing and sintering at temperature of 1300 ^{0}C, formed low quartz and indialite, which have hexagonal crystal structure with no others structure as can be detected in the ceramic body.

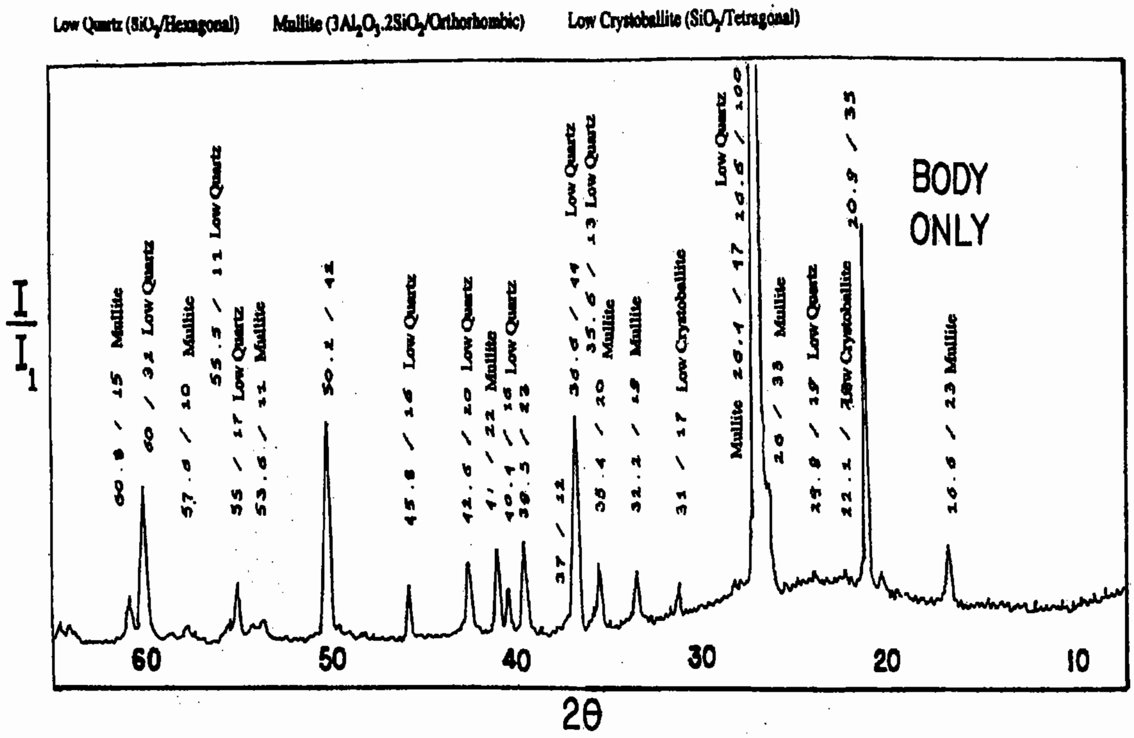

Figure 4. X-ray diffraction pattern of non-glaze ceramic body.

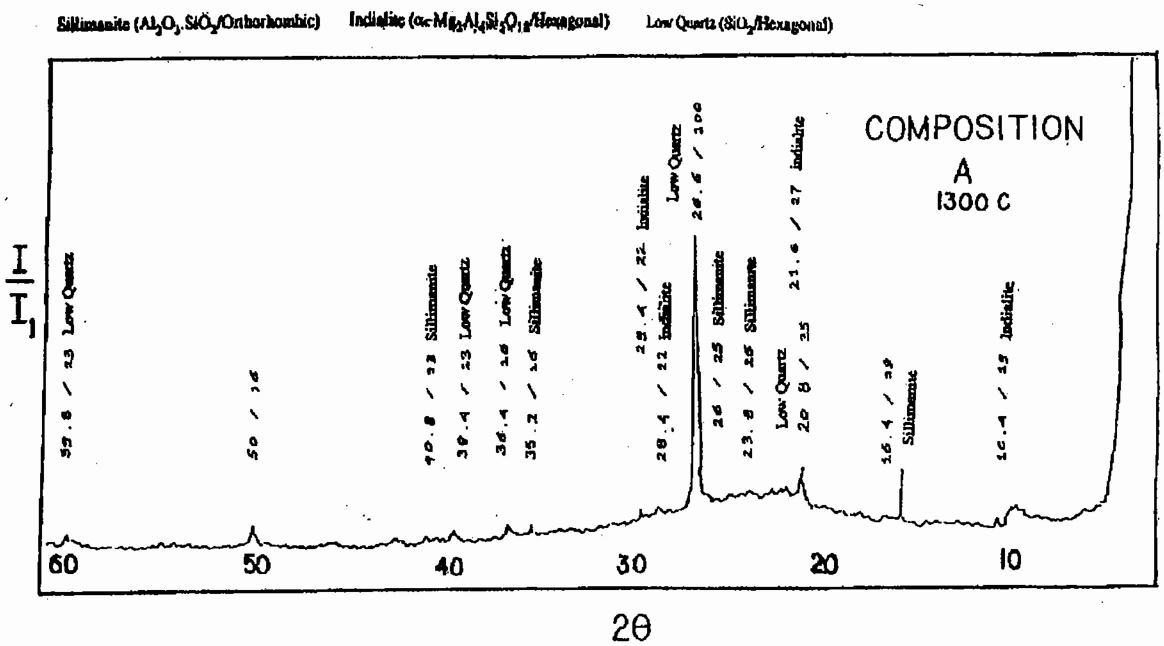

Figure 5. X-ray diffraction pattern of glazed ceramic of sample A.

Low Quartz (SiO_2/Hexagonal) Indialite (α -$Mg_2Al_4Si_5O_{18}$ / Hexagonal)

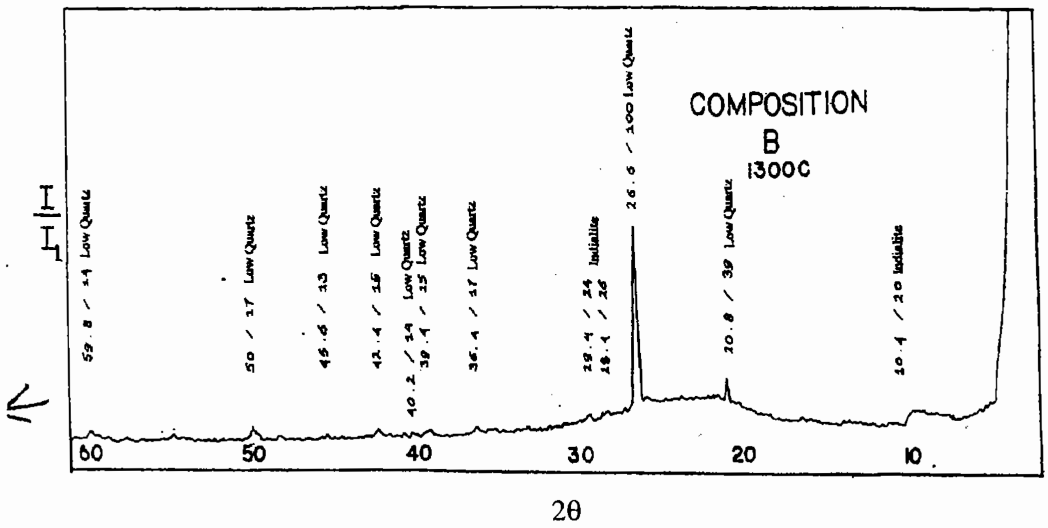

Figure 6. X-ray diffraction pattern of glazed ceramic of sample B.

CONCLUSION

Sintering 10 samples with glaze compositions ranging from A to F and holding for two hours at a firing temperature of 1300 ^{0}C shows that a composition A with 30 percent feldspars, 40 percent quartz, 20 percent kaolin and 10 percent talcum by weight formed a phase known through x-ray diffraction examination as sillimanite phase ($Al_2O_3.SiO_2$) which gave excellent isolator properties. While others composition notably glaze with composition B, C, D, and E formed a phase known as indialite with hexagonal crystal structure and has stoichiometry ratio as: α-$Mg_2Al_4Si_5O_{18}$. This phase is quite conductive and usually produces lower isolator properties. For highest feldspars composition of 55 percent by weight the reaction formed mullite phase ($3Al_2O_3.2SiO_3$) which is also gave good isolator properties. The existence of sillimanite phase with orthorhombic crystal structure gave excellent isolator properties, and couple with quartz phase produces high breakdown potential in particular for a composition A which is 173.15 kV/Cm. With a relatively high indiallite phase in the glaze for composition B than the glaze with composition C, D and E, these gave the lowest breakdown potential for composition B that is 85 kV/Cm.

Glazing has increased the mechanical strength (impact strength) of the ceramic body significantly, and ranging from 0.25 Kg-Cm to 0.77 Kg-Cm, and also decreases the porosities from 5.36 percent down to 1.06 percent. Therefore, medium voltage ceramic isolator for power transmission line can be fabricated more economically by balancing feldspars and quartz composition. High feldspars composition tend to improve the surface smoothness, as well as improve the glaze isolator properties. Hence, their application must be balanced either with high feldspar composition and low quartz or high quarts with lower feldspar composition.

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